CABLE SBIR Subtopics b. through h. Subtopics involving APPLICATIONS of CABLE Materials

of Topic 20 of DOE SBIR/STTR Phase I/ Release 2 JOINT TOPIC: CABLE MATERIALS AND APPLICATIONS

CABLE Applications Subtopics Table of Contents

CABLE TOPIC INFORMATION APPLICABLE TO ALL CABLE SUBTOPICS (20a-h)

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Phase I Applications: YES	Accepting STTR Phase I Applications: YES

The objectives of the Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and Thermal Applications (CABLE): Materials and Applications topic are 1) to transfer technology for the fabrication of breakthrough CABLE enhanced conductivity materials and 2) to support leapfrog applications in the design and use of enhanced conductivity materials that will make the performance improvements and energy savings of these applications more affordable.

This joint topic is a collaboration among the following EERE Technology Offices: Advanced Manufacturing, Building Technologies, Geothermal Energy Technologies, Solar Energy Technologies, and Vehicle Technologies as well as the DOE Office of Electricity [1]. Please refer to each office's specific topics for more information about each office.

The use of electricity in the U.S. and worldwide is currently undergoing multiple paradigms shifts in how electricity is generated, delivered, and consumed [2, 3]. There is a critical need for advances in the materials and means by which electricity is translated from generation to use. The demand for CABLE materials and applications are increasing as sectors become increasingly electrified [4]. In addition, there is an urgent need to upgrade electric systems for greater grid reliability because of increasing renewables and distributed energy resources (DERs), and resilience from evolving threats such as cyber-attacks and extreme weather offers a once in a lifetime window of opportunity to upgrade the fundamental materials and applications that support it.

While DOE has funded research on high conductivity materials before, the comprehensive CABLE approach mandates that a breakthrough in electrical or thermal conductivity be balanced with maintenance of other properties needed for applications above a certain minimum value, with minimum standards described in the application specific subtopics below. Furthermore, the CABLE material and its applications must be sufficiently broad and affordable that it enables leapfrogging international competitors and fostering a host of new manufacturing industries to make higher performing materials and the products—everything from transmission and electric vehicle (EV) cables to solar cells—enabled by them.

This topic supports the objectives of the Energy Storage Grand Challenge, Grid Modernization Initiative, and DOE's support for Advanced Manufacturing as part of its support for to advance the Industries of the Future. Advancements in CABLE materials also support the objectives of the Critical Minerals Initiative.

This topic comprises two distinct, complementary focuses critical to achieve the CABLE objectives.

CABLE materials innovations are the subject of subtopic a) where enhancing conductivity—a "breakthrough, leapfrog" improvement compared to state of the art—must be balanced by meeting all applicable minimum standards for future commercialization of applications (including subtopics b-h). Note that the nano-carbon infusion approach of subtopic a is only one of many promising approaches (many of which also involve the use of critical materials) to make CABLE materials [5, 6, 7, 8,9]. Proposals for research on approaches other than that in subtopic a) are not, however, being sought under this Topic at this time.

CABLE applications (subtopics b-h) should include enhanced conductivity materials (from subtopic a) or other new materials [5 ,6, 7, 8] that meet or exceed metrics specified for each application and to the current state of the art. Even though these applications appear prosaic where substantial R&D effort has been made previously, the CABLE applications listed below, all have the potential to be Breakthrough and Leapfrog because for the first time the research includes re-designing for enhanced conductivity material—something never done before—and exploring the manufacturing and regulatory barriers involved in the use of such materials in pervasive applications.

Enhanced conductivity materials NOT of interest (or applications that rely on them) include:

- Standard superconducting materials;
- High-temperature superconducting materials; and
- Primarily magnetic materials;
- Proposals that focus on these materials will be deemed nonresponsive to this topic.

All proposals to this topic must:

- Propose a tightly structured program which includes clear, CABLE-relevant technical milestones/ timeline that demonstrate clear progress, are aggressive but achievable, and are quantitative;
- Provide evidence that the proposer has relevant CABLE and/or OE/EERE experience and capability;
- Clearly define metrics and expected deliverables;
- Explain applications of project output and potential for future commercialization;
- Include projections for cost and/or performance improvements that are tied to a clearly defined baseline and/or state of the art products or practices;
- Explicitly and thoroughly differentiate the proposed innovation with respect to existing commercially available products or solutions;
- Include an energy savings impact and impact grid as well as a preliminary cost analysis;
- Report all relevant performance metrics; and
- Justify all performance claims with theoretical predictions and/or relevant experimental data.

The Phase I application should detail material, design and/or bench scale systems that are scalable to a subsequent Phase II prototype development. Applications must be responsive to the following subtopics. Applications outside of these subtopic areas will not be considered.

CABLE Q&As for Subtopics b-h

Q: Where can I obtain conductivity-enhanced material for the Conductivity-enhanced materials for Affordable, Breakthrough, Leapfrog Electric and thermal applications subtopics 20b-20h.

A: CABLE – Conductivity-enhanced materials for Affordable, Breakthrough Leapfrog Electric and thermal Applications (CABLE) are not, to DOE's knowledge for sale commercially. This lack of availability is why, in addition to the CABLE SBIR subtopic 20a, the DOE will soon roll out several new efforts to support the CABLE material and applications research ecosystems. For the latest updates and with questions, write to CABLE.BigIdea@hq.doe.gov In addition, the particular conductivity-enhanced material that is made with a carbon-infusion process can be licensed from ANL as indicated in subtopic 20a. UPDATE: On December 22, DOE approved a CABLE virtual workshop to be held early April 2021 (See https://cable-bigideas.anl.gov/workshop) to bring together conductivity-enhanced materials inventors (and manufacturers) with SBIR proposers and other SME interested in affordable applications of conductivity enhanced materials in everything from motors to microelectronics.

Q: Must I use the conductivity enhanced material from 20a my application (in 20 b-h)?

A: The material that is the subject of Subtopic a) – a TTO for an ANL patent – is only one of many CABLE materials that could be incorporated in proposals for subtopics b) through h). Other potential conductivity-enhanced materials proposers might use are highlighted in CABLE Topic references 5, 6, 7, 8. Very shortly, we will roll out a CABLE material-focused activity that will help us identify and verify still more conductivity-enhanced materials for you to use in your proposals. But you are Not required to use the conductivity enhanced materials we identify. If you already have your own material that is optimized for one of the b)-h) applications, please feel free to use it in your proposal even if it's not on our list.

Q: What is the desired TRL at the end of Phase I?

A: We are looking for a proof-of-concept from Phase I, in the range of TRL 2-4.

Q: What is the desired TRL at the end of Phase II?

A: Phase II is dependent on the progress made in Phase 1, but we would preliminarily be seeking TRL 3-6.

CABLE Subtopic b: Electricity Delivery System Applications

This subtopic solicits innovative research and development (R&D) proposals that can enable breakthrough applications to better secure the national grid and make efficiency and affordability improvements to electricity delivery system (EDS) infrastructure. This subtopic is being jointly supported by the Office of Electricity and the EERE Advanced Manufacturing Office.

The U.S. electricity delivery system is currently undergoing a transformation as the importance of grid reliability and resilience is realized in the face of evolving threats (including cyber-attacks and extreme weather), and state and local policies increase penetration of renewable energy and distributed energy resources (DERs). To ensure reliable and secure electricity delivery in the future grid through these changes, technological advancements in transmission & distribution (T&D) infrastructure must be made [1]. Specifically, improvements are required in T&D infrastructure, and at their most fundamental, the material that transports power: conductors, and their application in transmission cables.

This subtopic seeks proposals to integrate affordable high-performance conductors into transmission and distribution applications to provide numerous benefits to EDS and other power-carrying applications (including overhead, underground and underwater cables). Lines or cables with significantly improved conductivity yield transmission benefits including minimized losses, increased strength, reduced sag and improved carrying capacity, all of which improve performance and operations. Improved-performance conductors promise immense benefits to all system stakeholders [2]. To the grid operator, the benefits from installing advanced lines and cables include increased grid reliability and resilience. To the customer, use of such lines and cables results in significant cost savings. The primary goal of this subtopic is to design a proof-of-concept conductor for medium- to long- distance transmission lines and cables. In performing this design research, both desired properties and design specifications must be considered.

Desired properties of conductors for EDS applications include [3]:

- Low resistance to minimize electricity loss.
- Improved mechanical strength for maximized reliability.
    - Improved tensile strength.
    - Improved mechanical bend fatigue performance.
- Improved thermal conductivity.
- Improved melting points to maintain high operational strength.
- High ductility for mechanical flexibility.
- Earth-abundant content for minimized cost.
- Recyclable and safe material end-of-life.

Maximizing one or several of these properties in the proposed conductor design is a priority of this subtopic. In addition, proposals to this subtopic must explain how they support OE's goals for innovative transmission reliability, resilient distribution systems, energy storage, and advanced grid components. Proposals are encouraged to draw upon AMO-sponsored innovations in advanced material manufacturing, particularly for high performance conductors. Advanced manufacturing approaches such as additive manufacturing and roll-to-roll are encouraged where appropriate.

Use of a breakthrough in one property must be complemented by maintaining the other properties above minimum accepted values, with minimum standards described in each area of interest below. This is to balance a "breakthrough, leapfrog" improvement with minimums that support applicability and future commercialization. Expected improvements in metrics and how the improvements compare to the current state of the art must be clearly stated in proposals in response to this subtopic. Designs should maximize economic performance, demonstrate financial viability, and establish a credible pathway to commercialization.

A related consideration is meeting external design parameters. Rural utilities and co-operatives generally rely on USDA Rural Utility Service (RUS) specifications (and minimum accepted values) for designing and implementing electric infrastructure in their jurisdiction. Designing conductors that may be used in these areas removes one barrier from future commercialization potential. Properties of interest in these standards are more practical for the electric delivery application and include:

- Operating voltage
- Line current
- Conductor Size
- Max operating temperature
- Line voltage drop
- Power losses

The specific standards may be found at: https://www.rd.usda.gov/files/UEP_Bulletin_1724E-200.pdf [4]. The linked standards detail aboveground cables specifically, but RUS also publishes standards for other applications, including underground cables. Following federal standards in designing these conductors may benefit future commercialization opportunities and will make the project more appealing to a wider market. While it is not strictly required to meet any specific set of RUS standards, or every single standard in this research, keeping them in mind while designing an advanced conductor proof-of-concept will be favorably viewed by reviewers.

Areas of interest for this topic include:

1. **Aluminum-Based Conductors**: Aluminum is primarily used for overhead transmission lines, as it provides high-conductivity and light-weight benefits for low cost. The most common aluminum-based conductors are aluminum conductor steel reinforced (ACSR), but other on-the-market options include ACCC, ACCR, and ACSS. As a material, aluminum has potential for overhead lines, and advanced manufacturing methods may yield unique advancements for aluminum-based conductors [5]. Table 1 describes desired minimum values for several properties of the proof-of-concept aluminum-based conductor. Due to the variable nature of properties of differently sized conductors, precise values may change depending on size and ampacity chosen of the conductor design. As stated earlier, these thresholds are approximate guidelines for property thresholds to maximize commercialization potential in the future; it is expected that the design meets CABLE goals with an affordable, breakthrough, and leapfrog design.

Property	Desired Threshold	Notes
Electrical conductivity	> 62% IACS	
Mechanical strength	Comparable to or stronger than that of on-the-market ACSR	Precise value may change depending on line rating
Resistance	< 0.2 Ω/1000ft	DC at 20°C
Ductility	Comparable to or stronger than that of on-the-market ACSR	Precise value may change depending on line rating
Cost	Should not exceed $2/foot finished product	May be substantially lower depending on line rating and manufacturing methods

2. **Copper-Based Conductors**: Copper-based conductors benefit from high conductivity and high strength but suffer from higher weight and costs. For medium- to long- distance transmission, these properties may make copper apt for underground or underwater applications, because the higher conductivity and strength increase reliability and efficiency. Aluminum-based conductors are by far the most common conductors for transmission applications, and thus there are fewer preferred requirements for a copper-based conductor. The proposed design should achieve over 100% IACS and must display viable application for undersea or underground cabling. Of utmost importance are minimizing cost while maximizing strength and conductivity. Discussing demonstrated viability for transmission application that may lead to future commercialization will help in the proposal.

3. **Other EDS Applications**: Not limited to strictly aluminum-based or copper-based conductors, there are other advanced technologies that support the specific goals of CABLE while bringing benefit to EDS.

Proposals will be considered in the following areas. Adherence to standards and demonstrated grid-scale viability is essential to maintaining a strong application.

- Aluminum/ Copper composite materials
- Other conductor materials or cable designs that align with CABLE goals
- Grid-viable projects that support advanced materials integration into transmission infrastructure. This may include:
- Grid resilience and reliability innovations
- Advanced insulating materials for high-voltage application
- Conductor coatings for harsh conditions

This subtopic supports the Grid Modernization crosscut, emphasizing advancements for future grid architecture and technologies.

Questions – Contact: Benjamin Shrager, Office of Electricity, Benjamin.shrager@hq.doe.gov

Q&A (Subtopic b)

Q: Is a new or adapted alloy design for high conductivity aluminum responsive to this topic as long as the approach is innovative and may result in a "leapfrog" effect in the technology area? Would an incremental improvement not be responsive? Alternatively, is there more desire to focus on conductive carbon containing metals (e.g., composites, covetics)?

A: To your first question, yes, a responsive topic in this area should demonstrate a breakthrough/ leapfrog improvement for EDS T&D line metrics. A design that does not contain improvements to any metrics that can be considered breakthrough or leapfrog are unresponsive. We do not have a desire to focus on any specific solution.

Q: Can you please confirm if the topic seeks to look at the materials that make up a conductor component (e.g., ACSR cable), or at the component itself?

A: You may focus either on the conductor component, as outlined in Areas of Interest i and ii, or on other T&D line/ EDS improvements that would work to meet the goals of CABLE as outlined in the main CABLE topic description.

Q: In the table describing the desired attributes of the conductor, it indicates a cost of $2/ft or better. Could you please confirm that this is a single strand of wire, and that in includes processing costs?

A: Yes, this is correct. The $2/foot refers to finished product, which includes manufacturing costs.

Q: While maintaining strength or ductility, is it desired to take a look at potential improvements to corrosion or creep resistance?

A: Because both properties are desired for T&D lines, they are of interest in your design. One is not preferred over the other, and it should be noted how these improvements complement other metrics or properties you expect to see in your design. For the latest updates and with questions, write to CABLE.BigIdea@hq.doe.gov In addition, the particular conductivity-enhanced material that is made with a carbon-infusion process can be licensed from ANL as indicated in subtopic 20a. UPDATE: On December 22, DOE approved a CABLE virtual workshop to be held early April 2021 (See https://cable-bigideas.anl.gov/workshop) to bring together conductivity-enhanced materials inventors (and manufacturers) with SBIR proposers and other SME interested in affordable applications of conductivity enhanced materials in everything from motors to microelectronics.

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Q: What is the desired TRL at the end of Phase I?

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Q: What is the desired TRL at the end of Phase II?

A: Phase II is dependent on the progress made in Phase 1, but we would preliminarily be seeking TRL 3-6.

References (Subtopic b)

1. De Martini, P. "Future of U.S. Electric Distribution." EEI, PNNL, October 2010, https://gridarchitecture.pnnl.gov/media/white-papers/2012%20Jul-Future%20of%20Electric%20Distribution.pdf

2. U.S. DOE. "Quadrennial Technology Review 2015, Chapter 3: Enabling Modernization of the Electric Power System." U.S. DOE, 2015, https://www.energy.gov/sites/prod/files/2015/09/f26/QTR2015-3F-Transmission-and-Distribution.pdf

3. U.S. DOE, Office of Electricity. "Transformer Resilience and Advanced Components (TRAC) Program." U.S. DOE, June 2020, https://www.energy.gov/sites/prod/files/2020/06/f75/TRAC%20Program%20Vision%20and%20Framework.pdf

4. U.S. Department of Agriculture. "Design Manual for High Voltage Transmission Lines." Rural Utilities Service, Electric Staff Division, 2009, https://www.rd.usda.gov/files/UEP_Bulletin_1724E-200.pdf

5. Balser, A., et al. "Effective Grid Utilization: A Technical Assessment and Application Guide." NREL, September 2012, https://www.nrel.gov/docs/fy13osti/53696.pdf

6. MISO. "Transmission Cost Estimation Guide." MTEP19, 2019, https://cdn.misoenergy.org/20190212%20PSC%20Item%2005a%20Transmission%20Cost%20Estimation%20Guide%20for%20MTEP%202019_for%20review317692.pdf

7. Socariceanu M., An X., Deighton A., Friday A. "Corrosion assessment of aluminum conductor for medium voltage cables for Subsea umbilical system." Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering – OMAE v. 5, 2018, https://asmedigitalcollection.asme.org/OMAE/proceedings-abstract/OMAE2018/51241/V005T04A012/287423

CABLE Subtopic c: Non-metallic Heat Exchangers

This subtopic solicits proposals for next-generation non-metallic heat exchanger systems to improve the energy efficiency of heat pumps and air conditioners over a broad range of operating conditions for building and industrial applications that leverage CABLE non-metallic materials with enhanced thermal conductivity.

Current state-of-the art, air-to-refrigerant heat exchangers typically use copper-tube, aluminum-fin construction, with internal enhancement in the tubes and lances or louvers in the fins to promote heat transfer. Metal derived heat exchanger designs are today's state-of-the art (SOA) heat exchangers, like microchannel heat exchangers (MCHX).
Prior R&D investment by DOE have looked at, high performance compact heat exchanger, low charge heat exchanger designs and rotating designs. The development of polymer or non-metal heat exchange designs are ideal due to their light weight, manufacturing potential, wide range of geometric design possibilities, corrosion resistance, and potential to be low cost. Polymer heat exchangers have not taken off as a practicable solution due to their relatively low thermal conductivity.

Considering the potential advantages non-metallic enhanced conductivity materials afford, this subtopic seeks new designs for heat exchangers suitable for condensers or evaporators in air conditioners or heating-only heat pumps, as well as heat exchangers suitable for both condensing and evaporating for reversible heat pumps. All solutions must have the potential to enable the market acceptance at scale.

Given the wide range of technology suitable for this subtopic, specific application targets are not defined but proposed innovations must exceed the state-of-the-art performance significantly. Applications must demonstrate progress in Phase I and achievement in Phase II of the following performance and cost targets:

Non-metallic Heat Exchangers	
Requirements	**Targets**
Performance, heat transfer rate (UA)	> 500% compared to state-of-the-art designs
Physical size	> 50% reduction compared to state-of-the-art designs
Fan, blower, or pump parasitic energy consumption	> 30% reduction compared to state-of-the-art designs
Required cleaning intervals, or difficulty of cleaning, to maintain as-new performance	Little to no increase as compared to state-of-the-art designs
Susceptibility to damage or corrosion or performance degradation during manufacture, assembly, transportation, installation, or use	Little to no increase as compared to state-of-the-art designs for relevant applications
Defrost requirements (for applications such as outdoor air-to-refrigerant heat exchangers)	Little to no increase as compared to state-of-the-art designs
Material Cost	> 40% lower cost compared to Aluminum design, lowest-cost material/designs

Please refer to Topic 12 (BTO) for other opportunities related to Building technologies.

Questions – Contact: Fredericka Brown, Building Technologies Office, Fredericka.brown@ee.doe.gov

Q&A (Subtopic c)

Q: What is definition of non-metallic—what about a coating with metal nanoparticles

A: Coating a regular (e.g., aluminum (Al) or Copper (Cu)) heat exchanger is NOT responsive. Metal (Al and Cu) heat exchanger designs are today's heat exchangers (HX) used by manufactures. The development of polymer or non-metal heat exchange designs are ideal due to their light weight, manufacturing potential, wide range of geometric design possibilities, corrosion resistance, and potential to be low cost. Polymer heat exchangers have not taken off as a practicable solution due to their relatively low thermal conductivity, the focus of this SBIR topic. *A polymer HX is responsive.* A polymer HX that uses highly conductive (metal or nonmetallic) particles or fibers to increase the thermal conductivity would be responsive. The references for this topic give insights into the state-of-the art for non-metallic HX and their challenges.

References (Subtopic c)

1. Goetzler, W., Guernsey, M., Young, J. "Research & Development Opportunities for Joining Technologies in HVAC&R." US DOE, October 2015, https://www.energy.gov/sites/prod/files/2015/10/f27/bto_hvacr_joining_report_oct2015.pdf

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5. Rupprecht L. "Conductive Polymers and Plastics in Industrial Applications." *Plastics Design Library*, Norwich, NY, 1999, https://www.sciencedirect.com/book/9781884207778/conductive-polymers-and-plastics

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CABLE Subtopic d: Ice-storage and Other Thermal Storage-related Systems

This subtopic solicits proposals for high performance (efficient and cost-effective) ice-based thermal storage technologies that leverage CABLE enhanced thermal conductivity materials.

The water-ice phase change is attractive for thermal (cold) energy storage because of its large heat of fusion resulting in high energy density, low cost, near constant storage temperature (melt temperature) along with minimal environmental impact. Applications of ice storage include heating, ventilation, and air-conditioning (HVAC) and refrigeration technologies, including direct expansion and chilled water, load balancing, integrating renewable energy sources into the grid, etc.

During ice storage charging, a heat transfer fluid at a lower temperature is used to form ice, and during discharging, the process is reversed and ice melts into water and the heat transfer fluid is cooled down. The challenge with ice storage is that ice is a relatively poor thermal conductor. Thus, as ice is formed it becomes kinetically prohibitive to form more ice, limiting the total amount of stored energy over a fixed period. Typically, extensive piping is used to increase the total energy stored. Moreover, this approach leads to increased overall footprint and cost of the storage systems often making them marginally- or non-economical.

This subtopic therefore will support proposals that look to overcome these issues associated with thermal energy storage through new materials and thermal control approaches. This subtopic is interested in both passive and active approaches such as novel materials, high conductivity reinforcements, tunable conductivity, and use of external stimuli to control thermal conductivity.

Key metrics for such technologies are shown in the table below. The first row highlights one of the most important areas needing improvement: the time it takes or the rate at which the storage systems are charged and discharged. Applications must demonstrate progress in Phase I and achievement in Phase II of the following performance and cost targets.

High Performance Ice Storage Systems	
Requirements	Targets
Performance (charging/discharging rate)	>200% over current state of the art systems
Energy storage density (kWh/m3)	>80
Round Trip Efficiency (%)	>90%
Footprint	>50% reduction from the current state of the art ice storage systems
Durability/Reliability/Life-time	Similar or better than current state - of-the-art ice storage systems
Energy Storage System Cost ($/kWh)	<25

Please refer to Topic 12 (BTO) for other opportunities related to Building technologies.

Questions – Contact: Fredericka Brown, Building Technologies Office, Fredericka.brown@ee.doe.gov

Q&A (Subtopic d)

Q: Is there a particular subset of ice-storage that is of interest as an affordable, breakthrough, leapfrog application using enhanced-conductivity.

A: An example might be replacing resistance heating for ice removal from the ice maker with energy efficient thermal release for removing ice using a high thermal conductivity material.

References (Subtopic d)

1. "Thermal Energy Storage for Space Cooling, Technology for reducing on-peak Electricity Demand and Cost." DOE/EE-0241, 2000, https://www.osti.gov/servlets/purl/770996

CABLE Subtopic e: Electric Systems—Generators and Motors

This subtopic solicits proposals for more affordable, efficient direct current (DC), single-phase and three-phase alternating current (AC) electric motors/generators that leverage innovations in CABLE materials. Generator/motor systems with integrated power conversion system innovations that improve overall system performance are also of interest.

In 2019, the U.S. used 37.1 quadrillion Btu (quads) of primary energy to generate electricity for the grid and consumed approximately 13.75 quads of site electricity in 2018 [1, 2]. Of this, nearly 98 percent of the electricity came from mechanical generators [3]. On the demand side, electric motors consumed more 50 percent of all electrical energy in the US and more than 85 percent of industrial electrical energy. [4] Both generators and motors rely on electrically conductive materials. Generators convert mechanical power into electrical power while motors convert electrical power into mechanical power. Improving the performance of motors and generators is critical to the U.S. energy system. Advances in CABLE materials provide significant opportunity to increase the power density of motor and generator technologies while reducing energy losses, increasing performance, and providing for better and/or lower complexity thermal management of these systems. Proposals are sought in the following two areas of interest:

- Electrical generator technologies have been used in hydropower for more than a century in power generation applications. Recent growth in the renewable energy sector has highlighted the need for more flexible, efficient, and reliable technologies—particularly in distributed applications where continued innovation is needed to lower costs. Conventional grid connected generators are heavy, have a large form factor, and distributed systems must survive in harsh or extreme conditions, and often in remote and difficult to access locations (offshore wind and marine energy for example). This results in higher transportation and installation, operations, and maintenance (IO&M) costs and the need for complex thermal management systems – estimates suggest that operations and maintenance (O&M) costs make up 20%-30% of the lifecycle costs for offshore wind [2]. Advanced materials hold promise to meaningfully lower the cost of energy to end users by lowering the cost of O&M and through improvements to efficiency and capital costs.

- Motor-driven components used in heating, ventilation, and air conditioning (HVAC) and refrigeration are the highest energy consumers in the buildings sectors. Most of the residential and commercial equipment types covered in the residential and commercial sectors are covered by DOE energy conservation standards and industry standards such as ASHRAE 90.1. These standards continue to push manufacturers to consider both more efficient motors and variable-speed technologies, among other product design improvements, to meet more stringent minimum efficiency requirements. However, research efforts and incentives outside of DOE regulation would enable further reductions in motor-driven system energy consumption in the residential and commercial sectors.

Innovations in CABLE materials have great potential to increase the performance (including power density and reliability) of both motor and generator systems. Proposals for research that improve technologies in both motors and generators are of particular interest. Examples of broad research efforts that could improve both motor and generator system performance while reducing lifecycle costs include:

- Advanced manufacturing including additively manufactured parts and components;

- Power conversion systems that use wide bandgap semiconductors in place of conventional semiconductor materials and incorporate CABLE materials;
- Generators with integrated speed changing mechanisms such as magnetic gears;
- Applications that simplify or eliminate the need for thermal management (for example active vs passive cooling, air vs water).

All proposals should demonstrate performance improvements that take full advantage of CABLE material improvements primarily:

- Increased electrical conductivity; and/or
- Increased thermal conductivity.

Secondary improvements that also should be considered in a proposed solution include, but are not limited to:

- Ampacity
- Magnetic permeability
- Other thermal performance (temperature coefficient of resistance)

All proposals must consider the reliability of proposed systems and environment in which they operate (humidity, corrosion).

Given the wide range of technology suitable for this subtopic, specific application targets are not defined but proposed innovations must exceed the state-of-the-art performance significantly. Efforts to reduce the cost of advanced motor and generator technologies are essential for commercialization. Applications must demonstrate progress in Phase I and achievement in Phase II of the following performance and cost targets:

High Performance Motor Targets	
Requirements	**Targets**
Efficiency and/or lower cost R&D focus	40% lower cost (same performance compared to state-of-the-art or Energy Star equipment)
Size and weight	No increase as compared to the most recent minimum energy efficiency standards
Susceptibility to damage or corrosion or performance degradation during manufacture, assembly, transportation, installation, or use	Little to no increase as compared to state-of-the-art designs for relevant applications
High Performance Generator Targets	
Requirements	**Targets**
Power density	5% increase in power density (as compared to current state-of-the-art)
Smaller form factor and/or lower weight	10% improvement for specific application (as compared to current state-of-the-art)
Thermal performance	Improved thermal tolerance and/or ability to manage externally
System reliability	Comparable or better as compared to state-of-the-art designs for relevant applications

This subtopic is seeking systems that achieve the highest combination of reductions of size, cost, form factor, thermal management, and largest improvements in performance.

Please refer to Topic 12 (BTO) for other opportunities related to Building technologies and Topic 17 (WPTO) for opportunities related to Water Power technologies.

Questions – Contact: Fredericka Brown, Building Technologies Office, Fredericka.brown@ee.doe.gov, and Erik Mauer, Water Power Technologies Office, erik.mauer@ee.doe.gov.

Q&A (Subtopic e)

Q: Are you implying that we want COMBINED motor and generator solution? Or a solution that could apply to both?

A: No, while such solutions may exist, proposers only need to focus either on the motor or the generator application.

Q. Where can I learn more about water generator options?

A: http://bit.ly/WPTOSBIRWebinar December 3, 3–4 p.m., hosted by WPTO and detailing WPTO-related topic areas https://bit.ly/35hCNCw

References (Subtopic e)

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https://www4.eere.energy.gov/wind/resource_center/resource/generatorse-sizing-tool-variable-speed-wind-turbine-generators

CABLE Subtopic f: Photovoltaics Module and System Electrical Connections

This subtopic solicits proposals for innovative technologies and approaches that improve the quality and performance of photovoltaic (PV) electrical connections at the cell, module, or system level while reducing their cost.

Metal conductors extract the charges that light generates in solar cells so they can flow to the rest of the solar array. These electrical conductors include the metal contacts on the solar cell, wiring, and connectors.

This subtopic seeks proposals for the application of new conductive materials and related technologies to advance the state of the art in two areas: cell and module metal contacts and interconnects and PV system electrical connections. Applicants must clearly indicate which of the two areas of interest being proposed.

1. Cell and module metal contacts and interconnects

There are strict requirements for making high-performance contacts and interconnects. Improvements in contacts are needed to increase the conductivity and durability while reducing their total cost of processing and raising the overall module performance. Applying the contact to the solar cell must: (1) not introduce too many recombination centers at the interface of the metal and the absorber material, because it would reduce the power output, (2) form an energetically favorable path at the interface for charges to move from the absorber material to the metal, and (3) be conductive enough to carry charges out of the cell without appreciable loss due to series resistance or shadowing. These technical requirements must all be met while maintaining low cost, reliability, durability over decades, and compatibility with the packaging materials and existing manufacturing processes. Meeting these requirements through the application of new materials has the potential to meet these requirements. A third of cell fabrication costs are attributed to metal contacts. Metal contact and interconnect costs are between 10% and 30% of the total module cost owing to the materials and processing costs.

Applications to this area should propose the development of new cell and module metallization materials and processes. Applicants are expected to include objectives and milestones targeting a recombination current density (Jo) of the metallization contact of less than 10 fA/cm2, contact shading < 3% of active area, a cell fill factor of greater than 80%, and improved durability under chemical, thermal, and mechanical stresses that a module will experience in the field. The total cost for the metal contact materials and manufacturing step should be less than half of current costs, and projects must show that final mini-module test structures have better energy yield than a comparable baseline that uses state-of-the-art technology.

2. PV system electrical connections

Innovations in wire management and cable attachment present an opportunity to extend system durability well beyond the traditional 25-30-year PV plant life. EERE's goal is to extend the operational life of PV systems to 50 years. Critical interfaces and conductors must be capable of maintaining low-resistance electrical pathways despite thermal cycling, moisture ingress, mechanical loading, and other environmental challenges. At the utility scale, designs that increase the mechanical robustness of cabling interfaces, such as the attachment point to a tracker or designs that increase the installation speed of a PV plant, may result in lower levelized cost of electricity (LCOE) through lower operation and maintenance (O&M) and capital expenditures (CapEx) costs.

Applications in this area must demonstrate improved durability under accelerated life testing commensurate with a 50-year system lifetime with equivalent or improved electrical conductivity. Novel solutions for integrated wire management, such as cabling embedded in module framing or racking, may improve resistance to animal and environmental damage, thus avoiding expensive repair and replacement costs over the life of the system. The goal of this subtopic is to double the durability of PV systems or residential cabling and cabling attachments while reducing both installation time and bill-of-materials cost by 10%. Applicants must demonstrate the improvement by relevant component-level testing, using state-of-the-art, commercially available products for comparison.

Please refer to Topic 16 (SETO) for other opportunities related to solar energy technologies other than module and system electrical connections.

Questions – Contact: solar.sbir@ee.doe.gov

Q&A (Subtopic f)

Q: Where can I learn more about the PV topic?

A: Solar SBIR webinar: bit.ly/SBIR-SETO-webinar.

Q: Which joints, contacts, or interconnects would need to be produced within the solar cell or module?

A: Joints: the joining of two or more metal materials (such as ribbons to busbars in the cells, or the joining of wires between modules). Contacts: the metal that collects charge from the absorber material. Interconnects: the metal used to connect between cells in a module.

Q: Would the design and development of a new innovative Pb-free solder alloy be responsive to this subtopic?

A: Yes, that is within the scope of this subtopic.

References (Subtopic f)

1. U.S. Department of Energy. “Photovoltaics.” US DOE, Office of Energy Efficiency and Renewable Energy, 2020, https://www.energy.gov/eere/solar/photovoltaics.

CABLE Subtopic g: Geothermal: Direct Use and Electricity Generation Applications

The Geothermal Technologies Office (GTO) collaborates with the geothermal community with the goal of increasing geothermal electricity generation and the use of geothermal heat pumps and district heating by 2050 [1]. This subtopic solicits innovative research and development projects using enhanced conductivity materials or technologies in subsurface reservoir/wellbore environments for geothermal direct use applications and/or at electricity-producing geothermal power plants in order to reduce the levelized cost of heat or electricity.

For both direct use and power plants, GTO is seeking applications using enhanced conductivity materials to improve the thermal conductivity and heat transferred from the subsurface environment to the surface. For electricity-producing geothermal power plants, proposed materials and technologies must be designed for use in harsh downhole environments with elevated temperatures of greater than

225°C. For direct use applications, temperatures are typically lower than for electricity-producing power plants, but many similar technical challenges exist. Applications may include, but are not limited to the following:

- Improved wellbore materials such as high-conductivity cement or grout;
- Working fluids that optimize the net energy capture; and/or
- Improving the thermal conductivity within the geothermal reservoir.

Applicants must include performance targets for the proposed technology that can be benchmarked to comparable state-of-the art applications. Innovation into surfaced-based improvements, superconductive materials, or other types of standard operational efficiency improvements will be deemed non-responsive.

Please refer to Topic 1213 (GTO) for other opportunities related to geothermal energy technologies other than subsurface applications of enhanced conductivity materials.

Questions – Contact: William Vandermeer, Geothermal Technologies Office, William.Vandermeer@ee.doe.gov

Q&As (Subtopic g)

No Questions at this time.

References (Subtopic g)

1. U.S. Department of Energy. "GeoVision: Harnessing the Heat Beneath our Feet." Geothermal Technologies Office, U.S. Department of Energy, 2020, https://www.energy.gov/eere/geothermal/geovision

CABLE Subtopic h: Enhanced Conductivity EV Charging Cables and Couplers

This subtopic is soliciting proposals for the application of CABLE materials for new designs for wires and charging couplers for use in the recharging of electric vehicles.

As more and more vehicles are electrified, the energy losses in the charging couplers used to recharge these vehicles will continue to grow especially as ever faster charging powers are considered [1]. Improvements in the conductive materials used in the wire and contacts in the SAE J1772 DC charging coupler and cable, that operate at up to 400A and 1000V, are sought to reduce these energy losses.

Proposed improved material and coupler designs must consider all requirements for electric vehicle couplers including thermal, electrical, and other safety standards (e.g., UL 2202, UL 2251, ISO 17409, IEC 62196, IEC 60309) while not decreasing cable flexibility or increasing the weight from existing cable designs. The lifetime energy loss reductions from the proposed material and coupler design should be calculated for the entire cable system from the Electrical Vehicle Supply Equipment to the inlet of the vehicle for the lifetime of the cable. The impact of corrosion, fatigue, thermal degradation, and other impacts to the material lifetime should also be considered.

Please refer to Topic 17 (VTO) for other opportunities related to vehicle technologies.

Questions – Contact: Lee Slezak, Vehicle Technologies Office, Lee.Slezak@ee.doe.gov

Q&A (Subtopic h)

No Questions at this time.

References (Subtopic h)

1. U.S. Department of Energy. “Batteries, Charging, and Electric Vehicles.” US DOE, Office of Energy Efficiency and Renewable Energy, 2020, https://www.energy.gov/eere/vehicles/batteries-charging-and-electric-vehicles.

General References

1. For more information on the DOE offices that comprise CABLE see the following websites: Office of Electricity (OE) (https://www.energy.gov/oe/office-electricity); and those for seven Offices within DOE's Office of Efficiency and Renewable Energy (EERE): Advanced Manufacturing Office (AMO) (http://energy.gov/eere/amo), Building Technologies Office (BTO) (http://energy.gov/eere/buildings), Solar Energy Technologies Office (SETO) (https://www.energy.gov/eere/solar/solar-energy-technologies-office), the Geothermal Technologies Office (GTO) (https://www.energy.gov/eere/geothermal), the Vehicle Technologies Office (VTO) (https://www.energy.gov/eere/vehicles/vehicle-technologies-office); the Wind Energy Technologies Office (WETO) (https://energy.gov/eere/wind) and the Water Power Technologies Office (WPTO) (http://energy.gov/eere/water/water-power-program).

2. U.S. Energy Information Administration (EIA). "Annual Energy Review (AER) 2020." https://www.eia.gov/totalenergy/data/annual/

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9. Tehrani, Mehran "Advanced Electrical Conductors: An Overview and Prospects of Metal Nanocomposite and Nanocarbon Based Conductors", https://arxiv.org/submit/3454010/view

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